NGST

JPL Phase Retrieval Camera

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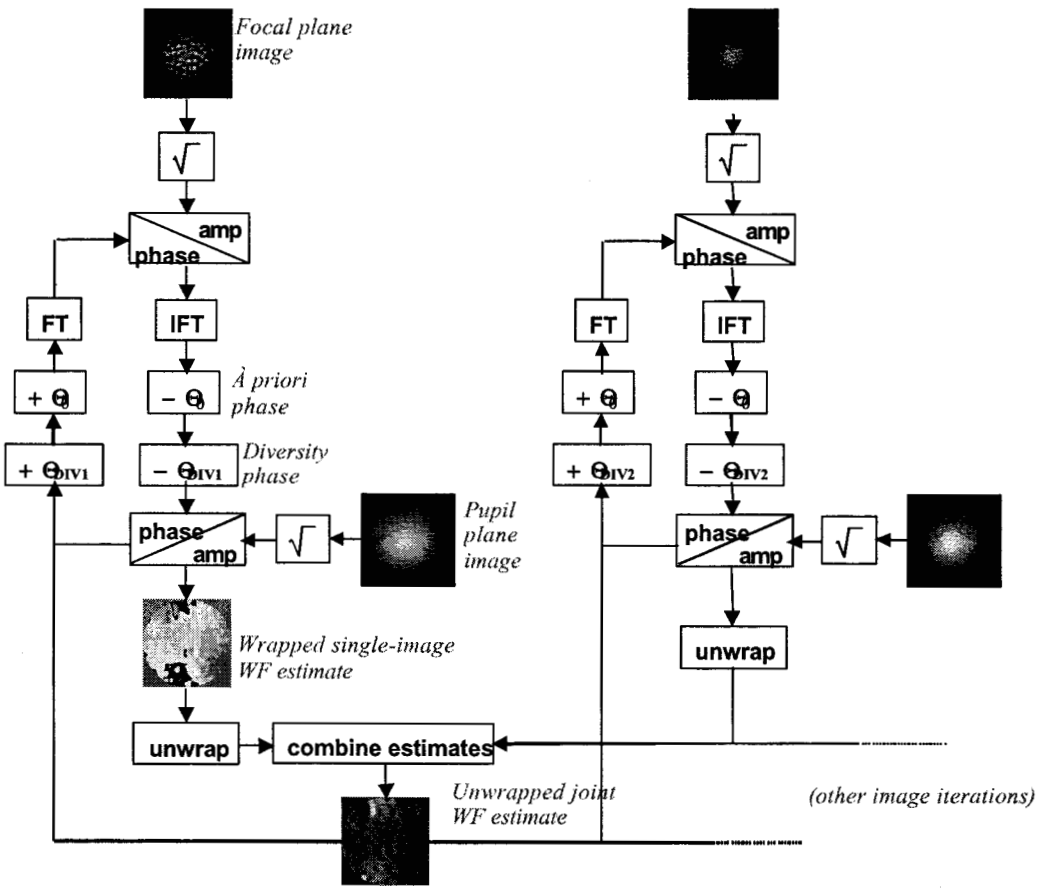
Overview

NGST

- NGST Phase Retrieval Camera (PRC) is a portable, self-contained device for phase retrieval wavefront sensing
- Useful for optical testing in high-jitter environments
  - MSFC test chamber for NMSD and AMSD mirrors
  - NGST Contractor testbeds
- Enables wavefront control experiments outside NGST's Wavefront Control Testbed (WCT)
  - Phase retrieval experiments
  - DM testing
  - Early experience sensing and controlling NGST primary optics
- Capitalizes on WCT hardware/software infrastructure

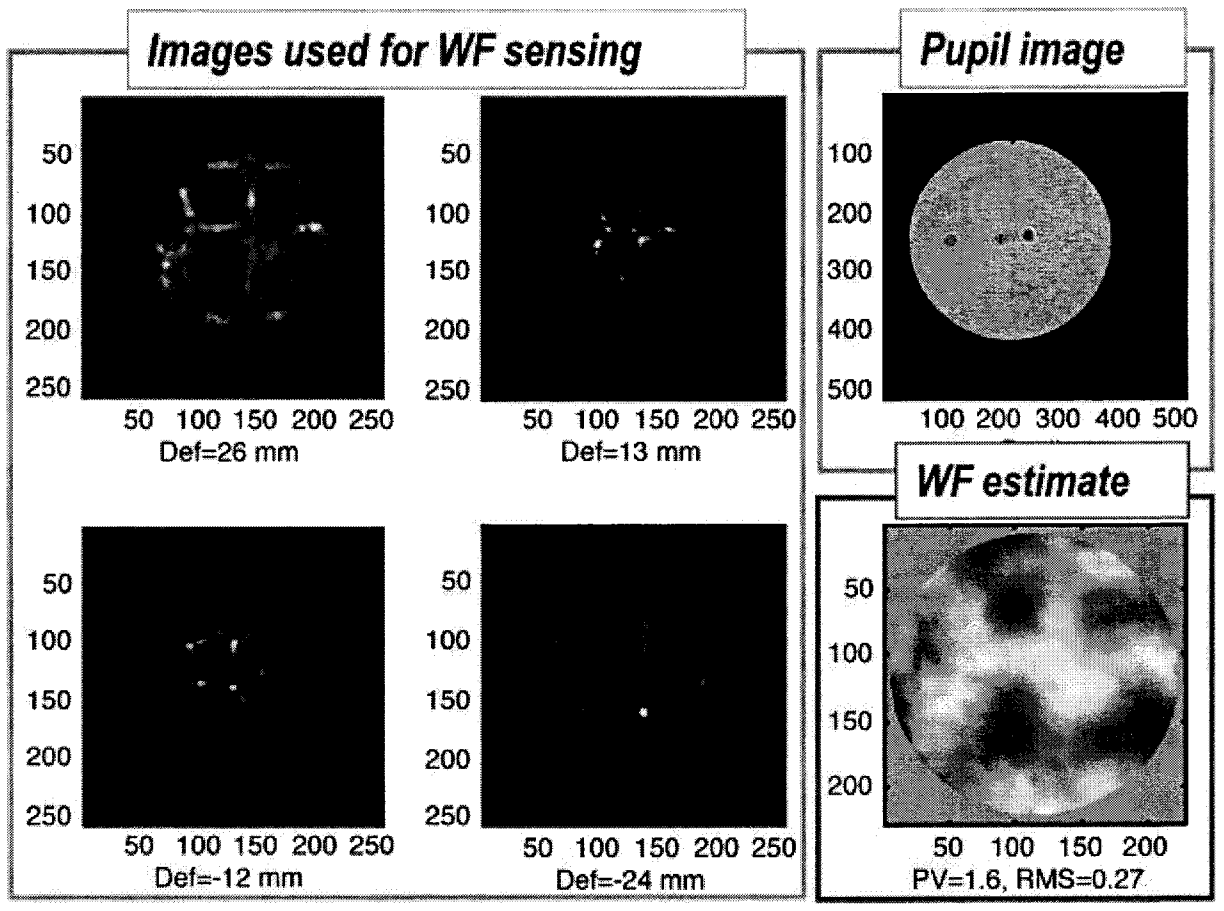
Modified Gerchberg-Saxton Phase Retrieval

NGST



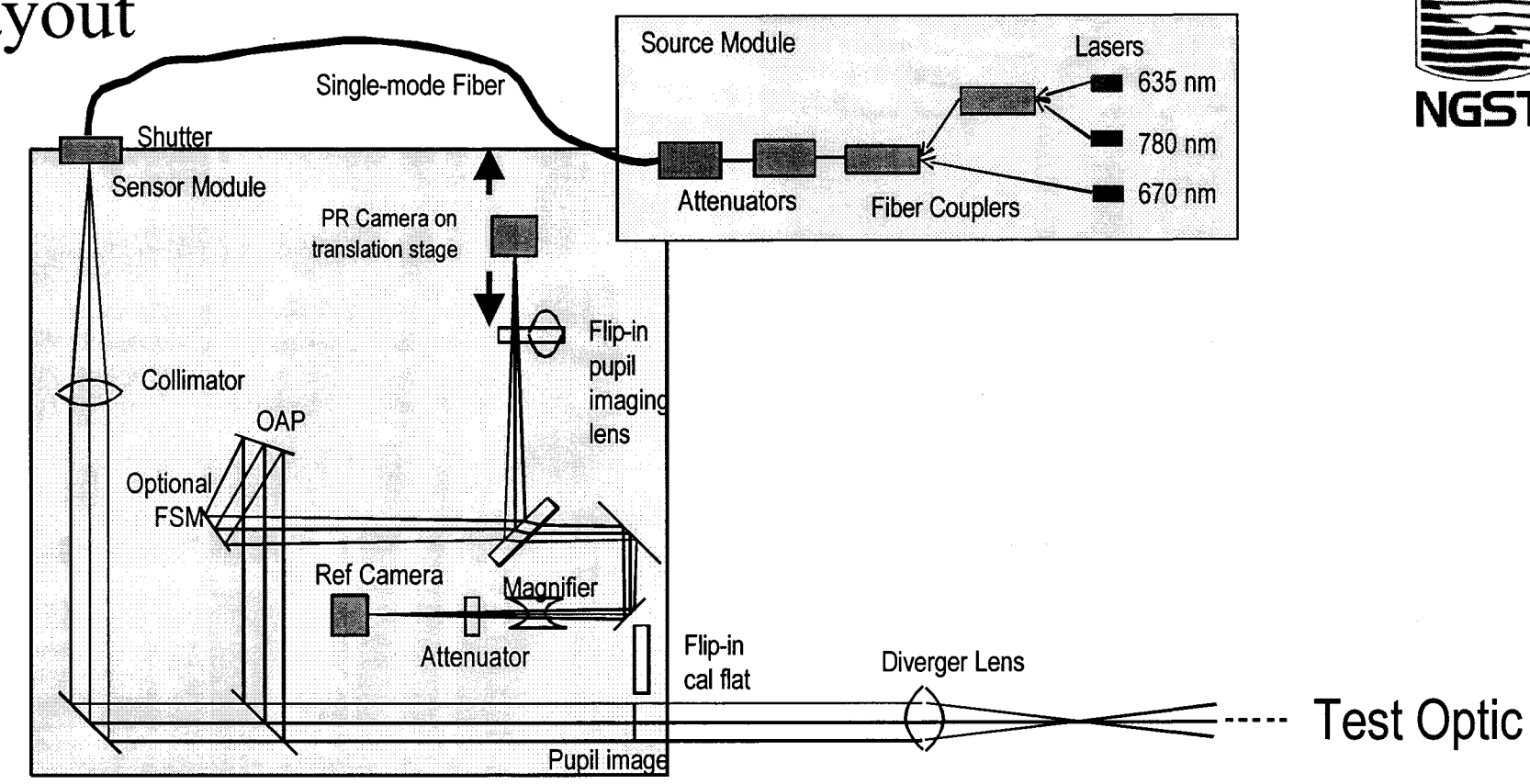
- Gerchberg-Saxton inner loop iterates between pupil and image planes
  - FT from pupil to image, IFT from image to pupil
  - Constrain field at image and at pupil by replacing amplitude with sqrt of image data
- Defocussed images improve visibility of aberrations
  - Spread out effects over many pixels
  - Reduce impact of jitter, other blurring
  - Reduce contrast between low, high-f effects
- Subtracting known phase (Θ_0, Θ_{DIV}) from the iteration reduces dynamic range
  - Θ_0 is systematic across all images
  - Θ_{DIV} is difference between images from embedded MACOS model
- Multiple images overdetermine solution to ensure uniqueness
  - Provides more data without introducing new unknowns
- Phase unwrapping allows estimation of WFE>λ
  - Joint unwrapping improves unwrapping robustness
- *Prescription Retrieval also used*
  - *Complementary algorithm provides more dynamic range, less spatial resolution*
  - *Used to find Θ_0*

WF Sensing Example



- WCT experience shows WF sensing performance:
  - Repeatibility = $\lambda_{633}/110$; PRC is better sampled and should do better
  - Range = a few waves P-V deviation from nominal
  - Relatively tolerant of jitter, lab seeing

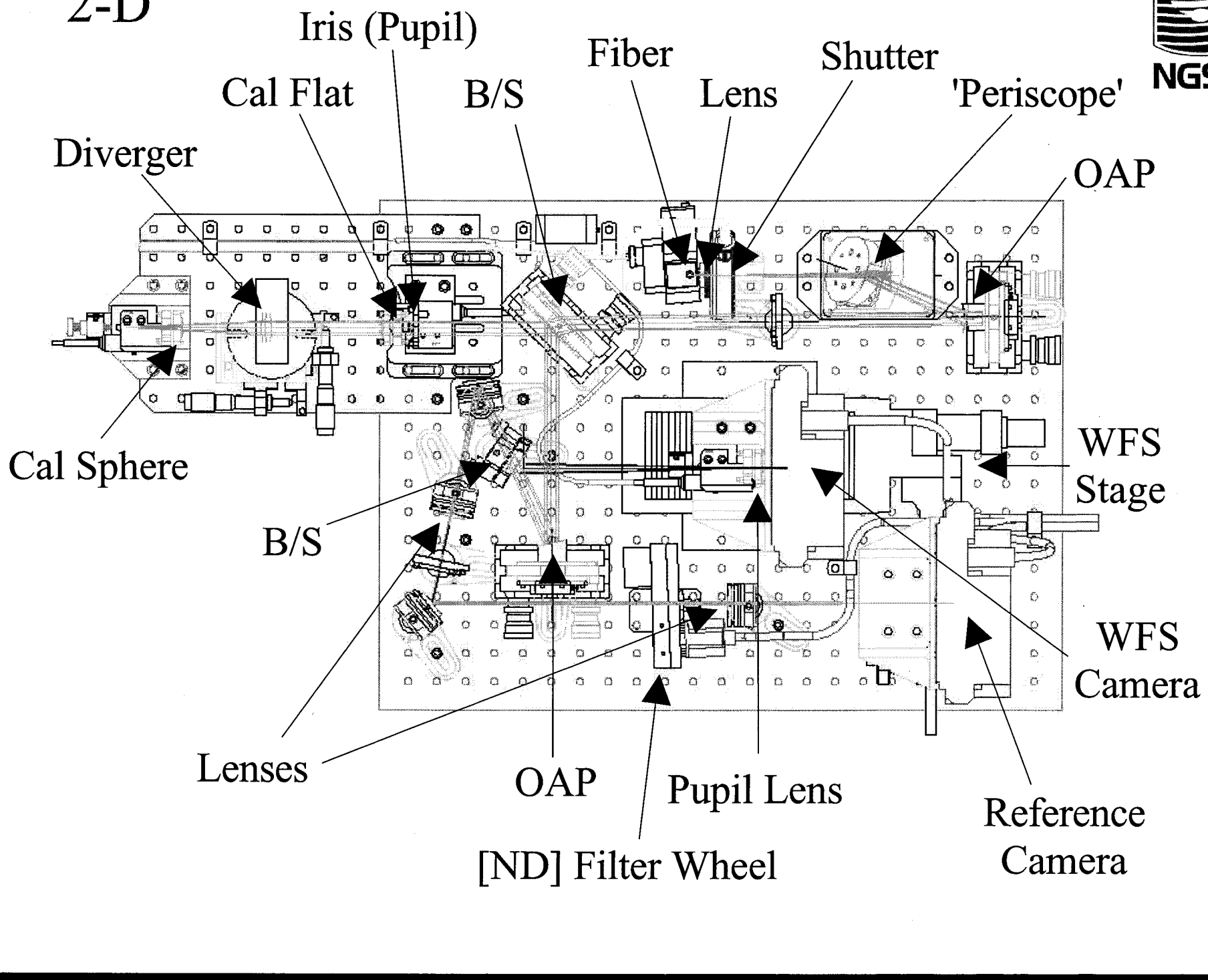
Layout



- 2- or 3-color source module for measuring segment piston
- 0.3 millisecond shutter to freeze seeing, jitter
- Test optic imaged onto iris (pupil) for telecentricity
- Camera on translation stage for WFS
- Reference camera to register boresight

2-D

NGST


Iris (Pupil)
Fiber
Shutter
Cal Flat
B/S
Lens
'Periscope'
Diverger
OAP
Cal Sphere
WFS
Stage
B/S
WFS
Camera
Lenses
OAP
Pupil Lens
Reference
Camera
[ND] Filter Wheel

Source Module

NGST

- Multiple fiber-coupled diode laser source
- Output from single mode fiber connected to sources by fiber couplers
- Fiber-coupled laser diodes
  - Wavelengths 635, 670, 780 nm readily available
  - Temperature and current stabilized diodes give high amplitude stability (0.1% variation over one hour)
- Inline fiberoptic attenuators control source flux

Phase Retrieval Channel

NGST

- Provides imagery for phase retrieval (including prescription retrieval) processing
- System telecentric in image space
- ~ Nyquist sampling (f/25)
- Science-grade CCD camera
  - 9 um pixels, TE cooler (+ 10 °C), 768 by 512 format, Photometrics SenSys
- Translation stage implements focus diversity
  - Newport 4" fast stage
- Flip-in pupil imaging lens
  - New Focus motorized flipper
- Flip-in flat provides for self-calibration
  - New Focus motorized flipper

Reference Channel

NGST

- Provides boresight jitter information
- Takes images simultaneously with PR images
  - Magnified (4X) in-focus PSF provides centroid accuracy
  - Neutral density filters permit full-well operation
    - Source intensity is varied to assure full-well in PR camera
    - Calibration with cameras in focus determines relative boresight
  - Jitter is common-path between cameras
    - Shift-and-add processing of PR camera images establishes correct centering for PR processing

Computers and Software

NGST

- PC travels with box to drive stages, grab images, provide communications to Executive
  - Utilizes modified WCT PC software
- Operated locally or remotely using SPARC workstation
  - Utilizes modified WCT Executive software
  - Phase and prescription retrieval
  - Internet-based communications
  - Matlab GUI driven
  - Parallel processing for speed (~3 minutes for phase retrieval)

Assembled Hardware

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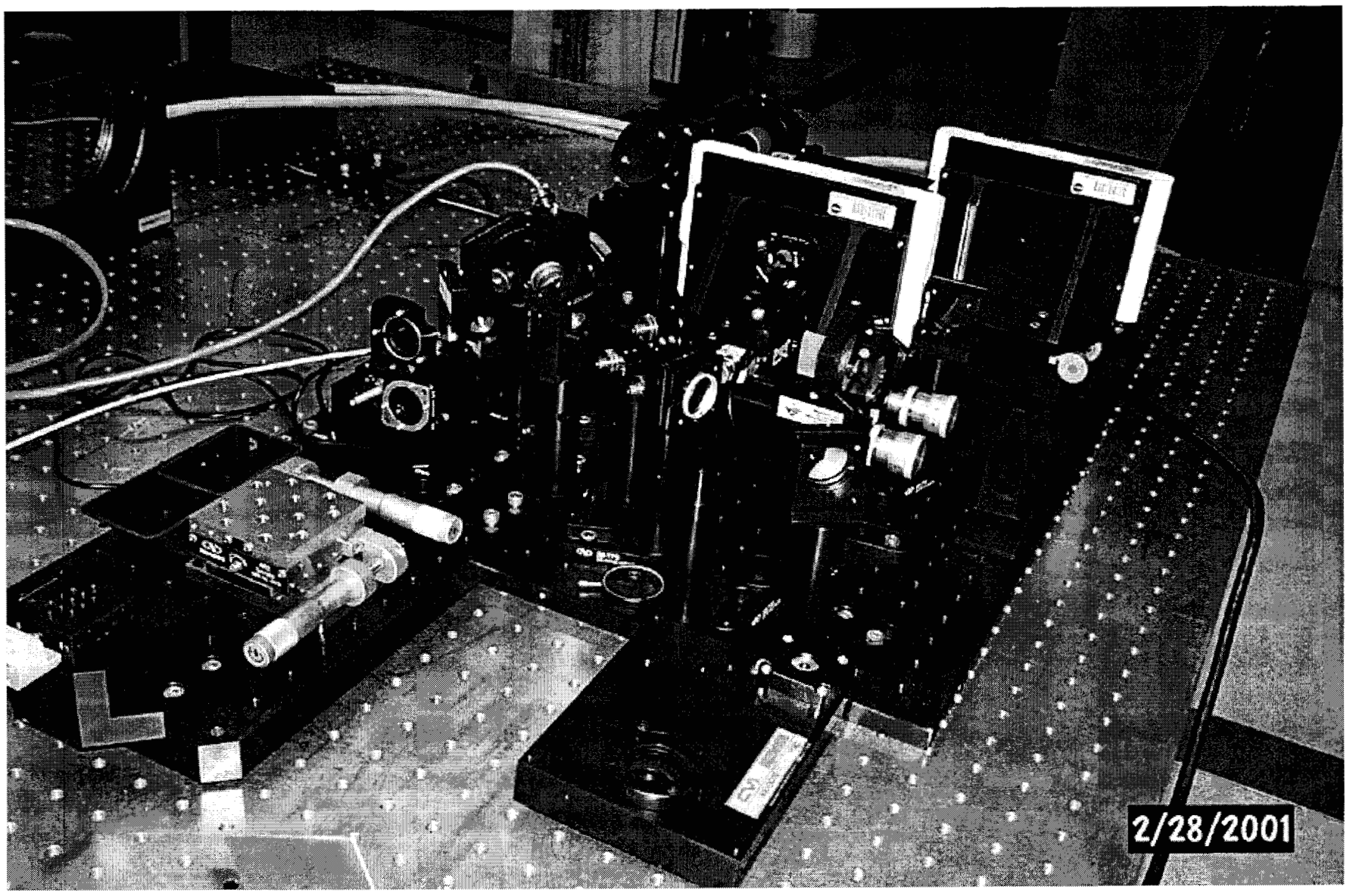

Calibration of F/# and Best Focus

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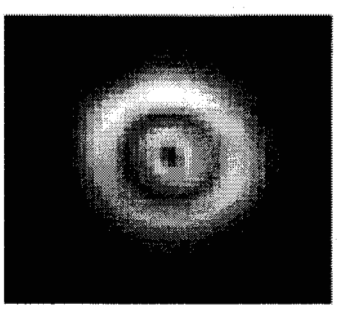
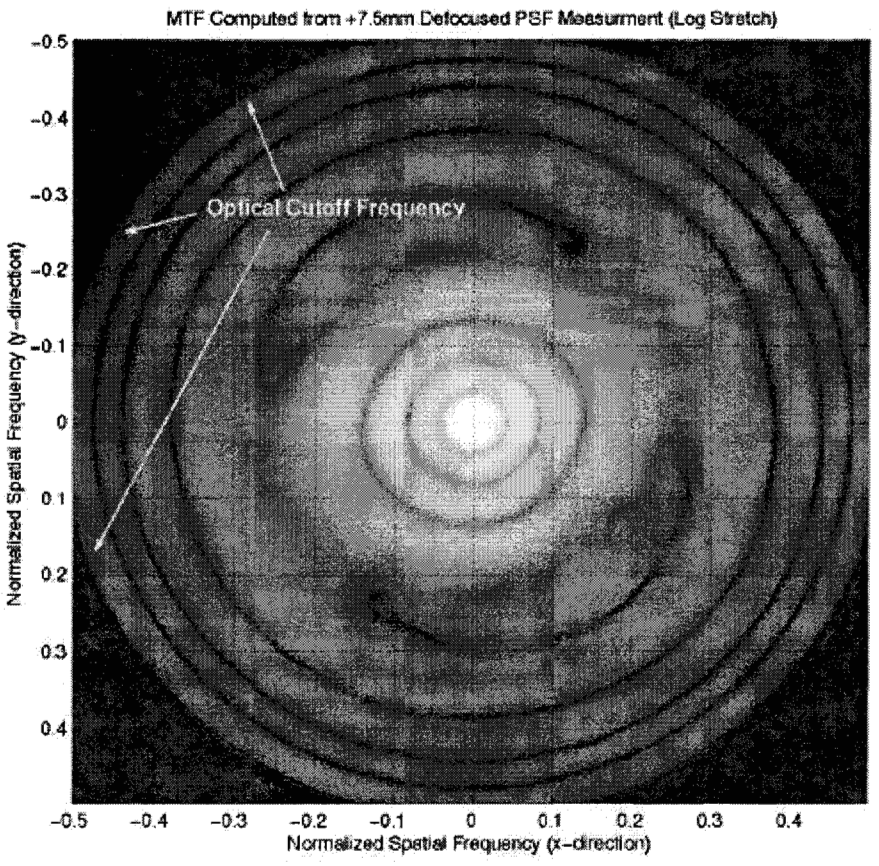
- The location of the optical cutoff frequency indicates that the system is about 4% undersampled with the fixed aperture.
- This also indicates that the F/# of the PRC is 25.6±0.1. (λ=675.5nm and Δ=9μm)
- By optimizing the defocus Zernikes to match the defocused PSFs we can calibrate both F/# and best focus.



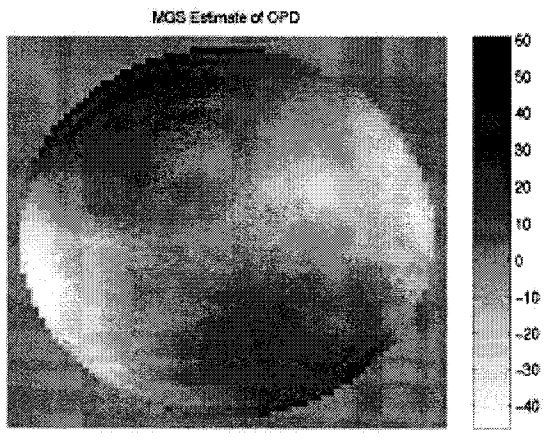
PSF measurement taken at +7.5mm, 10 frames co-added

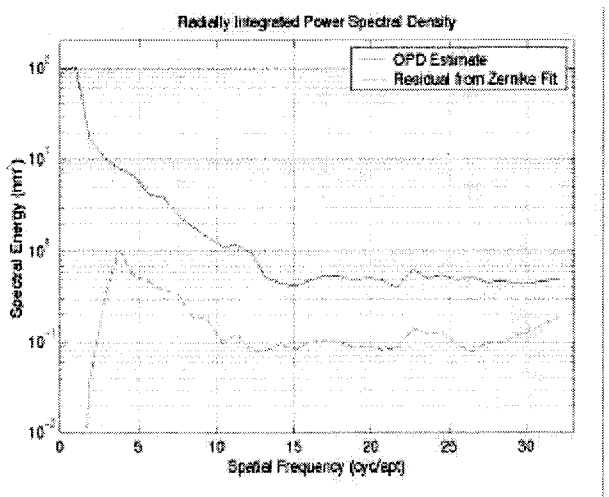
Parameter	Calibration
System F/#	25.5
Best Focus:	-2.84 mm
Inducible Defocus:	0.285 waves/mm

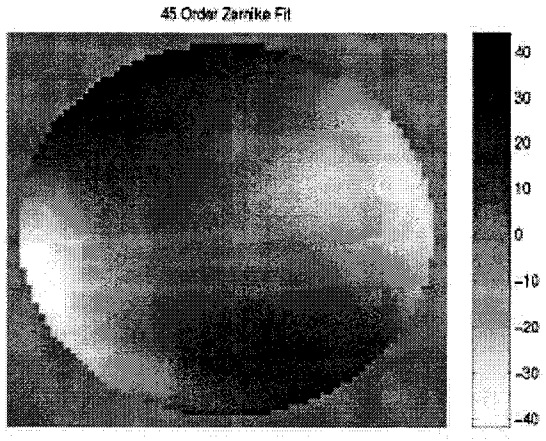


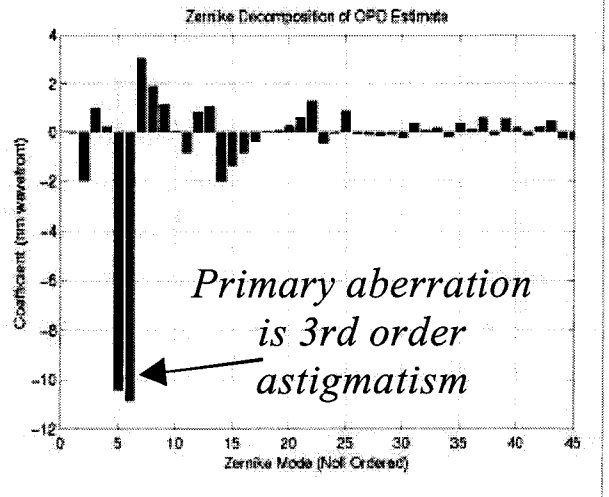
Phase Retrieval

- Used ±15mm and ±7.5mm imagery with the MGS algorithm
- Resulting OPD indicates 16.5nm (0.025 λ_{670}) rms wavefront error, primarily due to 3rd order astigmatism.





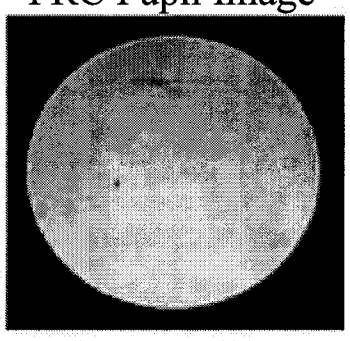


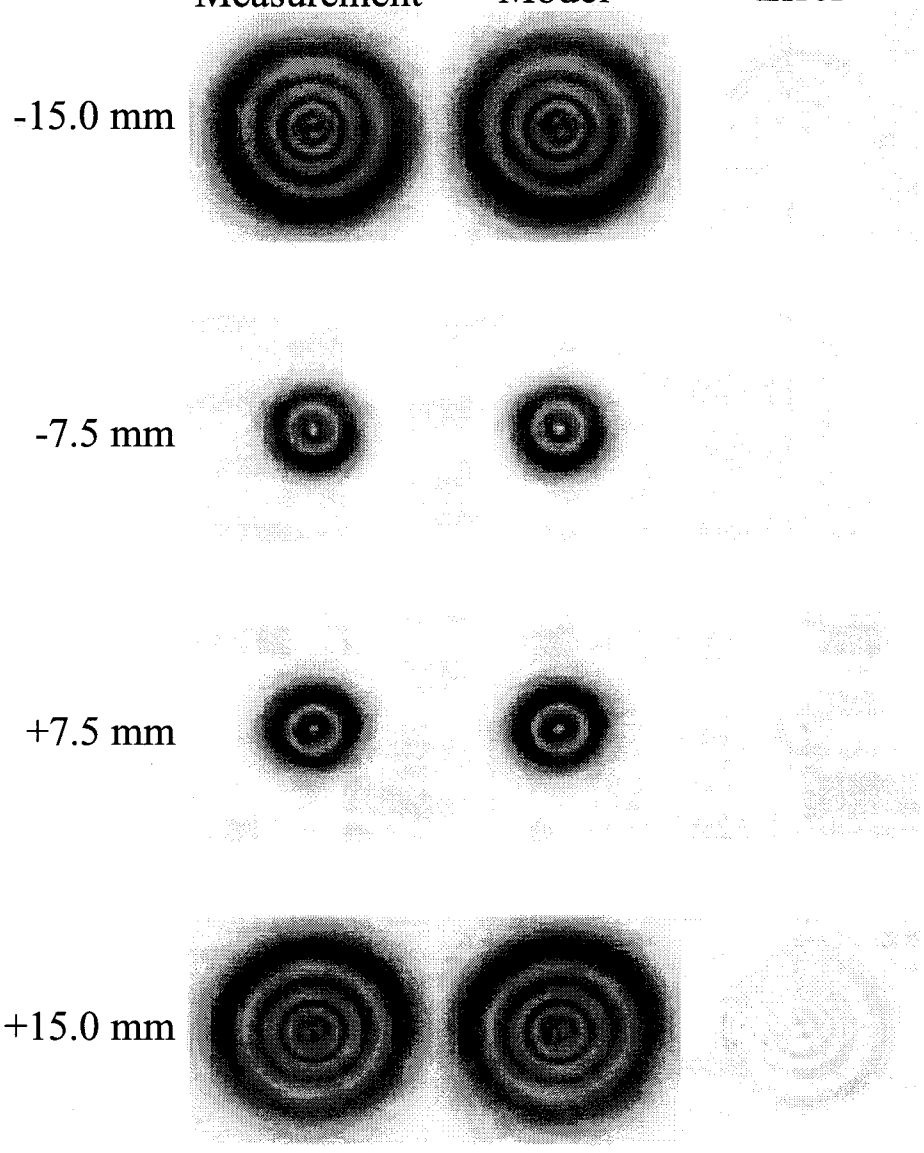


Phase Retrieval (continued)

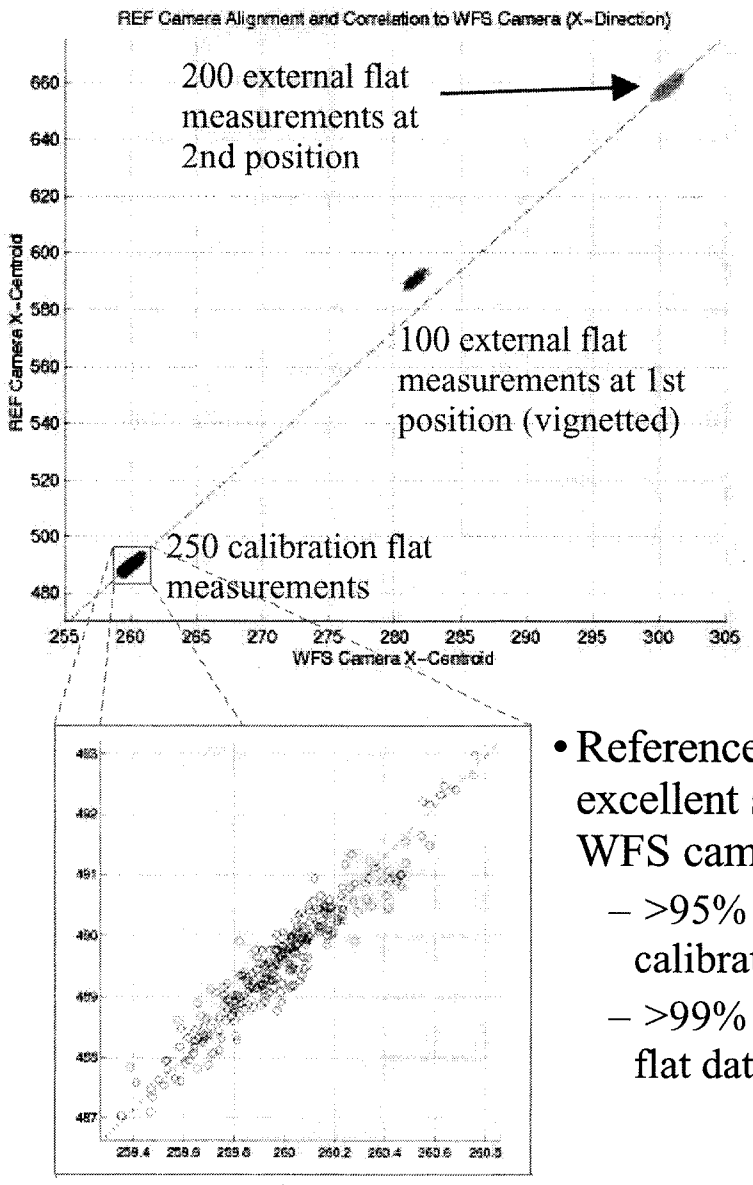
- OPD estimate from MGS provides a good fit over the set of defocused imagery.
- 0.2 pixel low-frequency jitter measured and modeled
- Fit improves by including a high-frequency (kHz) blurring kernel with σ=0.6 pixels
- Negative images are displayed to highlight modeling errors

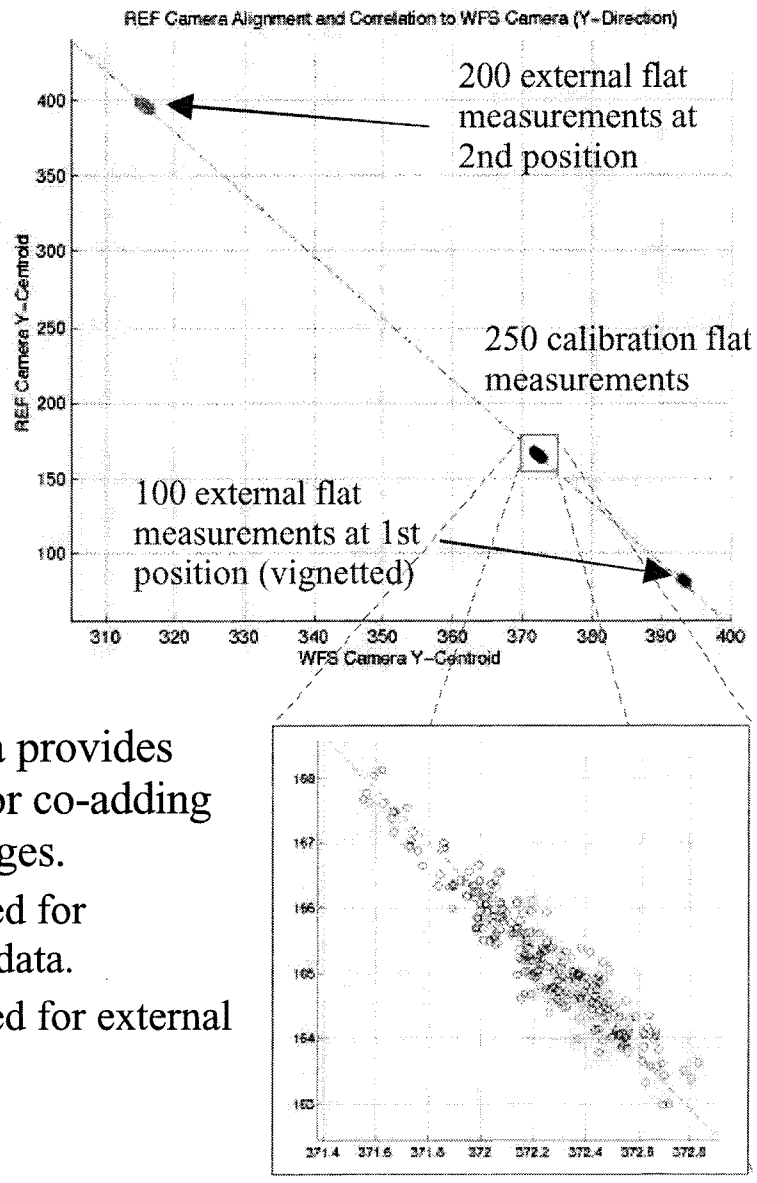
PRC Pupil Image





Reference Camera Magnification Calibration





- Reference camera provides excellent signal for co-adding WFS camera images.
  - >95% correlated for calibration flat data.
  - >99% correlated for external flat data.

Current Work

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- Calibration
  - Reference camera boresight shift with ND filter
  - Effect of shutters on internal jitter
  - WFS repeatability
- Optics
  - Fiber alignment (center illumination pattern)
  - OAP (reduce astigmatism) ???
  - Stake with epoxy
  - Install diverger lens
- Testing
  - Dynamic range
    - Low-quality spherical mirror + distorting mount
  - Compare to interferometer
  - High jitter cases

Conclusion

NGST

- Phase Retrieval Camera assembled, undergoing testing
- Good performance
  - Small internal wavefront error
    - 0.025 λ_{670} RMS
  - Small internal jitter
    - 0.2 pixels on wavefront sensing camera
    - Highly correlated with reference camera